Executive Summary

Squaw Lake has been a hypereutrophic lake with very poor water quality and water clarity. High nutrient levels support the growth of abundant planktonic and filamentous algae.

Since 1986, the concentration of phosphorus (nutrients) and chlorophyll (algae) has decreased and the water clarity has increased. The occurrence of filamentous algae was lowest in 2001.

Aquatic plant growth in Squaw Lake is limited by the soft water, steep littoral zone in some portions of the lake, fluctuating water levels, less favorable sediments for plant growth in the shallow zones and poor water clarity.

The aquatic plant community changed significantly between 1986-1989, stabilized during 1989-1995 and changed significantly during 1995-2001.

The plant community has changed from sparse plant growth, fair diversity and below average quality in 1986, to more abundant plant growth, average diversity and nearly average quality in 1989-1995, and finally to sparse plant growth, good diversity and below average quality in 1998-2001.

Squaw Lake is among the group of lakes in Wisconsin and the North Central Hardwood Region most impacted by disturbance. Fluctuating water levels and poor water clarity caused by abundant algae growth are likely the major disturbance factors and are determining the quality and composition of the aquatic plant community in Squaw Lake.

Management Recommendations

1) Address algae control through nutrient reduction and not through copper treatments. Cooperate with efforts to reduce the nutrient inputs to Squaw Lake.
    a) Cooperate with nutrient management programs in the watershed: responsible placement of manure, conservation practices on cropland. Inputs of nutrients from the watershed must be reduced.
    b) Discontinue any lawn fertilizer use that may be occurring on lakeshore properties.
    c) Maintain septic systems.

2) Protect and expand natural shorelines. Continue monitoring of the shoreline restoration demonstration sites.
    a) Expand the shoreline restoration projects to include more participants.
    b) Reduce the amount of cultivated lawn near the shore and allow buffer zones of native vegetation to develop.
    c) Re-vegetate eroded areas.
    d) Minimize the placement of hard structures and surfaces along the shoreline.

Changes in the Aquatic Plant Community of Squaw Lake
1986-2001
By
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I. INTRODUCTION

Studies of the aquatic macrophytes (plants) in Squaw Lake were conducted during July in 1986, 1989, 1992, 1995, 1998 and 2001 by Water Resources staff of the Western Central Region – Wisconsin Department of Natural Resources (DNR). The surveys are conducted as part of a statewide Long Term Trend Study. Aquatic macrophyte data is collected every three years and water quality data is collected every year on these trend lakes.

Long term studies of the diversity, density, and distribution of aquatic macrophytes are ongoing and will provide information that will be valuable for decisions about fish habitat improvements, designation of sensitive wildlife areas, water quality improvement, and aquatic plant management. Trend data can reveal changes occurring in the lake ecosystem.

Background

Squaw Lake is a 129-acre seepage lake, located in western St. Croix County. The lake is 0.2 miles wide and 1.2 miles long with a maximum depth of 32 feet. The lake has no outlet and an intermittent inlet.

The Squaw Lake watershed encompasses 1,967 acres and is composed of 61% cropland, 27% woodland, wetland and natural areas, 8% pasture and 2% residential development (Hess et. al. 1997). The watershed to lake ratio is 15:1; lakes with watershed area/lake size ratios greater than 10:1 tend to have water quality problems (Field 1994).

Algae blooms, winter fishkills and fluctuating water levels have been concerns in Squaw Lake.

History

Squaw Lake sediment cores were analyzed (Garrison 1991) to outline its paleolimnological history. Nutrient concentrations were stable during the 1700's and most of the 1800's. Nutrients started increasing during the latter part of the 1800's and increased more dramatically since 1940. Another sharp increase in nutrients since 1970 has caused the lake to become hypereutrophic (Garrison 1991).

Winter fishkills occurred on Squaw Lake in 1961-62, 1964-65, and 1985-86 (Engel 1988). Depletion of oxygen under the ice usually causes winterkills.

Squaw Lake has experienced problems with algae blooms for many years. Copper sulfate was applied annually from 1969-1984 (except 1980) to kill the algae.

Almost 7000 pounds of copper sulfate were added to the lake during this 15-year period. In 1985, the lake residents decided to discontinue copper sulfate treatments because of the inability of copper to produce any long-lasting improvements in water quality. Copper offers only temporary relief from algae; blooms can return within 10 days if the nutrients are still available and the water temperature is still favorable. In addition to being ineffective, copper can have adverse impacts on the aquatic plant community. Copper is toxic to aquatic invertebrates (an important food source for fish) and mollusks (clams and snails that are natural consumers of algae).

A watershed and lake management study were conducted to determine the sources of phosphorus contributing to the algae growth in Squaw Lake. The two leading sources of phosphorus in Squaw Lake's watershed were the winterspreading of manure (42%) and cropland run-off (41%) (Hess et. al. 1997). Recycling from the lake sediment was another important source, contributing 11% of the total phosphorus load (Sorge 1991).

Since 1951, the water levels in Squaw Lake have fluctuated 8 feet (Hess et. al. 1997). In 1987, drought caused a 3-4 foot drop in the lake level. As the water receded, smartweed began dominating the shore of newly exposed lake sediment. In 1989-90, rising water levels flooded the smartweed and other newly colonized emergents. These plants decayed and formed a nutrient rich layer on the lake sediments (Borman and Wilton 1989). In 1998, the water level was noticeably lower again.

II. METHODS

Field Methods

The same study design and transects were used for the 1986-2001 macrophyte studies and was based primarily on the rake-sampling method developed by Jessen and Lound (1962). Twenty-eight equal-distance transect lines were placed perpendicular to the shoreline with the first transect being randomly placed (Appendices).

One sampling site was randomly located in each depth zone (0-1.5ft, 1.5-5ft, 5-10ft, and 10-20ft) along each transect. Using a long-handled, steel, thatching rake, four rake samples were taken at each sampling site. The four samples were taken at each quarter of a 6-foot square quadrat. The aquatic plant species that were present on each rake sample were recorded. Aquatic vascular plants and algae that have morphologies similar to vascular plants, such as muskgrass and nitella are recorded.

Each species was given a density rating (0-5) based on the number of rake samples on which it was present, at each sampling site.

A rating of 1 indicates that a species was present on one rake
A rating of 2 indicates that it was present on two rake samples
A rating of 3 indicates that it was present on three rake samples
A rating of 4 indicates that it was present on all four rake samples
A rating of 5 indicates that it was abundantly present on all rake samples at that sampling site.

The presence of filamentous algae and the sediment type at each sampling site was recorded.

The type of shoreline cover was recorded at each transect. A section of shoreline, 50 feet on either side of the transect intercept with the shore and 30 feet deep, was evaluated. The percentage of each cover type within this 100' x 30' rectangle was estimated.

Visual inspection and periodic samples were taken between transect lines in order to record the presence of any species that did not occur at the sampling sites. Specimens of all plants present were collected and saved in a cooler for later preparation of voucher specimens. Nomenclature was according to Gleason and Cronquist (1991).

Data Analysis

The data for each year was analyzed separately and compared. The percent frequency of occurrence of each species was calculated (number of sampling sites at which it occurred/total number of sampling sites) (Appendices I-VI). Relative frequency was calculated (number of occurrences of a species/sum of all species occurrences) (Appendices I-VI). The mean density was calculated for each species (sum of a species' density ratings/number of sampling sites) (Appendices VII-XII). Relative density was calculated (density rating of a species / sum of all plant densities) (Appendices VII-XII). A "mean density where present" was calculated for each species (sum of a species' density ratings/number of sampling sites at which it occurred). The relative frequency and relative density were summed to obtain a dominance value (Appendices XIII-XVIII).

Simpson's Diversity Index was calculated for each sampling year (Appendices I-VI). Each sampling year was compared by a Coefficient of Community Similarity, which measures the percent similarity between two communities.

The Aquatic Macrophyte Community Index (AMCI) (Weber et. al. 1995) was calculated. Six parameters that characterize the aquatic macrophyte community (Table 11) are measured and the data for each is converted to a value 0 - 10 as outlined by Weber et. al. (1995).

The Average Coefficient of Conservatism and Floristic Quality were calculated to measure disturbance in the plant community (Nichols 1998). A coefficient of conservatism is an assigned value, 0-10, the probability that a species will occur in a relatively undisturbed habitat. The Average Coefficient of Conservatism is the mean of the coefficients for each species found in a lake. Floristic Quality is calculated from the Average Coefficient of Conservatism.

III. RESULTS

PHYSICAL DATA

Many physical parameters impact the macrophyte community. Water quality (concentration of nutrients and algae and water clarity, pH, hardness) influences the macrophyte community as the macrophyte community can in turn modify these parameters. Lake morphology, sediment composition and shoreland use also impact the macrophyte community.

WATER QUALITY

The trophic state of a lake can be determined by combining data that measures nutrient and algae concentrations and water clarity (Shaw et. al. 1993).
Oligotrophic lakes have low nutrients and biomass.
Eutrophic lakes are high in nutrients and biomass, often experiencing algal blooms.
Mesotrophic lakes are intermediate in nutrients and biomass.

Nutrients

Phosphorus is the limiting nutrient in many Wisconsin lakes. This means that the addition or reduction of phosphorus is the nutrient that will have the most impact on water quality. Therefore, phosphorus is measured as an indication of the nutrient status of a lake.

The phosphorus concentration in Squaw Lake has fluctuated widely 1986-2002, but have remained within the eutrophic range or hypereutrophic in some years (1988-1991, 1994-1997, 2000-2002) (Figure 1). Phosphorus has increased since 1999, but overall has declined since the late-1980's and mid-1990's.

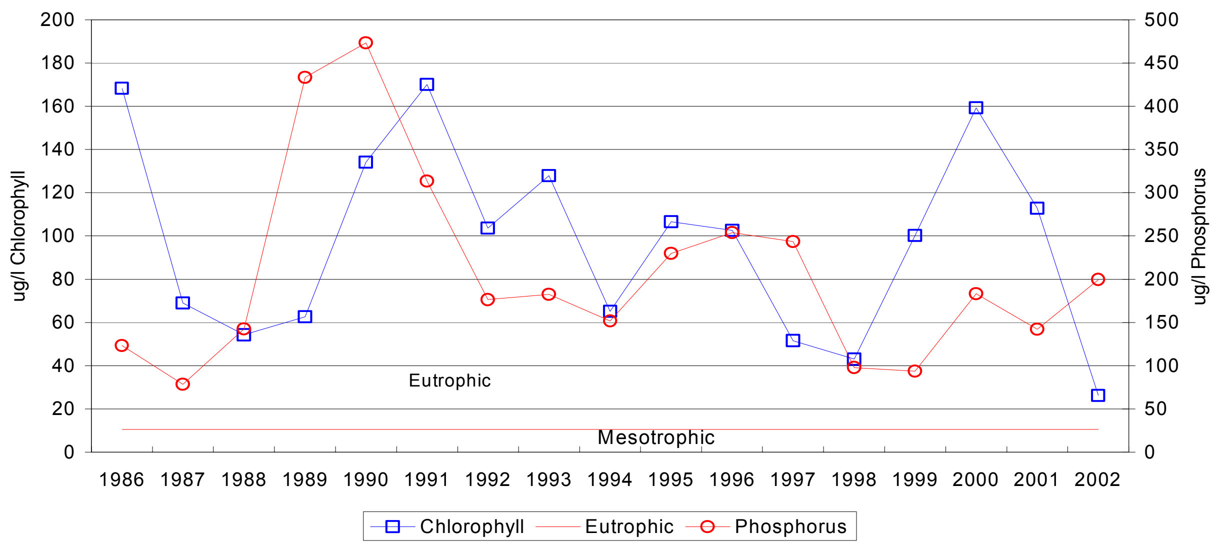


Figure 1. Mean summer phosphorus and chlorophyll concentrations in Squaw Lake, 1986-2002.

Algae

Algae is a natural and necessary part of a lake ecosystem, however, prolonged algae blooms can inhibit the growth of submersed vegetation by reducing water clarity, thus reducing light availability. Since algae cells contain chlorophyll, chlorophyll is measured to determine algae concentrations.

Chlorophyll in Squaw Lake has fluctuated widely within the hypereutrophic range (Figure 1). The pattern of changes in chlorophyll levels has followed the changing phosphorus levels in most years, but increased much more than phosphorus in 1986, 1993 and 1999. Chlorophyll has declined since 2000 and since 1986.

Although phosphorus is the limiting nutrient in most Wisconsin lakes, nitrogen can be the limiting nutrient in some. A lake is considered nitrogen limited when the ratio of nitrogen to phosphorus is less than 10:1 and transitional when the nitrogen to phosphorus ratio is between 10:1 and 15:1 (Shaw et. al. 1993). The ratio of mean summer nitrogen to mean summer phosphorus in Squaw Lake has fluctuated between 5.4:1 and 22.7:1. It appears that Squaw Lake is either nitrogen limited or transitional in most of the years it was studied. During those years, additions of nitrogen would feed algae growth.

Water Clarity

Mean summer water clarity, as measured with a Secchi Disc, has remained in the eutrophic/hypereutrophic range with poor to very poor water clarity during 1986-2002. Trend analysis shows a decline in water clarity since 1986. The best water clarity was in 1997; the poorest water clarity was in 2002 (Figure 2).

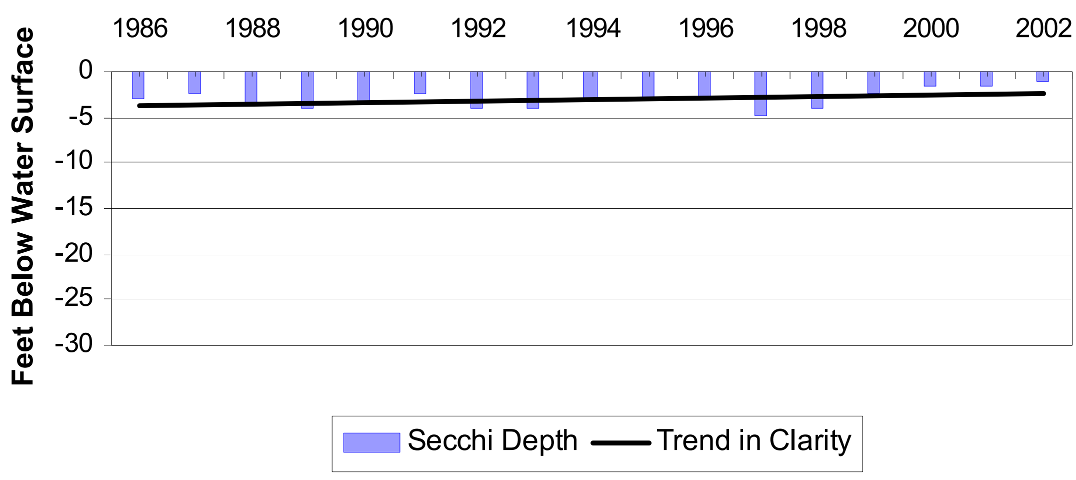


Figure 2. Water clarity in Squaw Lake, 1986-2002.

Volunteer lake monitors in the Self-Help Volunteer Lake Monitoring Program have collected water clarity data since 1988.

1988 – Jim Deltmann and Duane Haupt

1989- 1994 - Ernest Nelson

1995-2000 Bill Stute

2001- present - Ernest Nelson, Bill Stute and Patrick Gronlund

The volunteer data is valuable in that it is collected more frequently than DNR data (every two weeks to weekly), it is collected for a longer time span during the year (ice-out to ice-in), is collected at more locations in the lake and has been collected for many years.

The volunteer data shows a pattern of variability that is similar to the DNR data. The clarity in the North and South Basins were similar, but not the same (Figure 3).

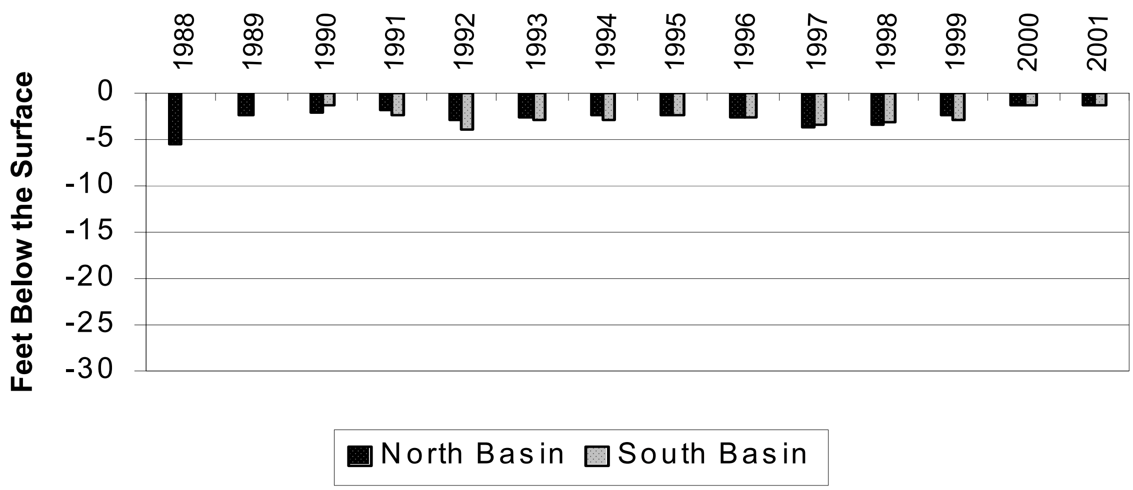


Figure 3. Mean summer water clarity, volunteer data, 1988-2001.

Volunteer data that was collected at the same time of the year was averaged to show the change in water clarity during the year. After ice-out, the water clarity improves in both basins of Squaw Lake through May and early June. The water clarity starts declining in July and reaches its lowest clarity in August. In late September the water clarity starts increasing again and attains the best clarity in October as temperatures cool and algae decline (Figure 4).

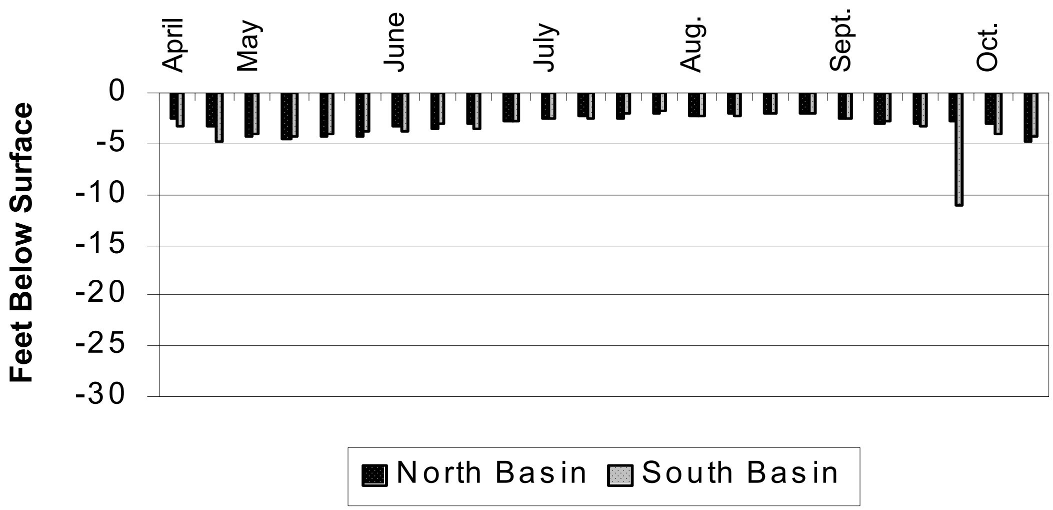


Figure 4. Change in water clarity during the season.

pH

The acidity or alkalinity of the water is measured by the pH. A pH of 7 indicates neutral water, less than 7 is acidic and greater than 7 is alkaline. The summer pH levels in Squaw Lake ranged between 6.78 and 10.4 during 1986-2002. This would favor plants adapted to a wide range of pH conditions. High pH in Squaw Lake likely due to photosynthesis as algae and plants remove CO_2 from the water column.

Hardness

The hardness levels in Squaw Lake, as measured by the amount of calcium carbonate, varied from 16-76 mg CaCo3/l with a mean of 22mg CaCo3/l. Hardness levels below 60mg CaCO3/l are considered soft water. Soft water lakes are more sensitive to the effects of acid rain and tend to have less plant growth.

LAKE MORPHOMETRY

The morphometry of a lake impacts the distribution of aquatic macrophytes. Duarte and Kalff (1986) found that the slope of the littoral zone accounted for 72% of the observed variability in the growth of submergent vegetation. Gentle slopes support a broader zone of potential plant growth than steep slopes (Engel 1985).

The littoral zone along the east and west side of Squaw Lake is steeper, limiting the area suitable for colonization by aquatic plants. Shallow bays and gradually sloped littoral zones occur at the north and south ends of the lake.

SEDIMENT COMPOSITION

Silt was the dominant sediment in Squaw Lake at the sample sites in 2001, especially at depths greater than 1.5ft (Table 1). Silt was found throughout the lake, more commonly at the deeper sites.

Sand/rock mixtures were dominant in the 0-1.5ft depth zone; organic muck was common in the 1.5-5 ft depth zone; sand/silt mixtures were common in the 5-10ft depth zone (Table 1).

Table 1. Sediment Composition, 2001

		0-1.5ft Depth	1.5-5ft depth	5-10ft Depth	10-20ft Depth	Overall
Soft Sediments	Silt	11%	25%	64%	81%	40%
	Muck		21%			6%
	Peat					
Mixed Sediments	Sand/silt	7%	11%	20%	12%	12%
	Silt/rock	3%		8%		3%
Hard Sediments	Sand/rock	39%	18%			16%
	Sand	11%	11%	8%	6%	9%
	Rock	18%	14%			9%
	Sand/gravel	11%				3%

There has been year-to-year variability in the occurrence of sediments at the sample sites in Squaw Lake. This is probably due to the fluctuating water levels in Squaw Lake. Since many sediment types were more common at certain depths, changes in water levels can change the location of the sites and alternately expose or inundate different sediment types.

Organic muck was frequently found at the sample sites in some years, especially in the bays, but did not occur in 1998 (Table 2). Organic muck had been found in the shallow water. Since the water level was down in 1998, the sites previously composed of muck sediments were likely terrestrial in 1998.

Table 2. Sediment Composition, 1986-2001

		1986	1989	1992	1995	1998	2001
Soft Sediments	Silt	10%	26%	28%	73%	38%	40%
	Muck	10%	24%	48%	4%		6%
	Peat					5%	
Mixed Sediments	Sand/silt					9%	12%
	Silt/rock				13	1%	3%
Hard Sediments	Sand/rock	29%	6%	2%	5%	22%	16%
	Sand	7%	22%	6%	1%	15%	9%
	Rock	11%	18%	2%	5%	3%	9%
	Sand/gravel						3%

WATER LEVEL

Squaw Lake has experienced fluctuating water levels, which stresses the aquatic plant community. The shallow zone becomes a terrestrial environment unsuitable for aquatic vegetation when the water levels drop. When water levels rise, macrophytes are suddenly placed in water that is too deep for light availability (Nichols 1975).

The submergent vegetation suffers equally, as the light availability at vegetated sites change with the changing water depth.

SHORELINE LAND USE

Land use practices strongly impact the aquatic plant community. Practices on the shore directly impact the plant community through increased sedimentation, increased nutrient levels from fertilizer run-off and introduced contaminants from farmland and urban run-off.

Wooded cover had the highest mean coverage and native herbaceous growth had the highest frequency of occurrence at the sites on Squaw Lake (Table 3). Native herbaceous growth occurred at all of the sites and also had a high coverage.

Cultivated lawn commonly occurred at the sample sites.

Some type of natural cover occurred at all of the sites and covered 91% of the shore, based on the sample sites. Some type of disturbed shoreline occurred at 32% of the sites and covered 10% of the shoreline (Table 3).

Table 3. Shoreline Land Use, 2001

		Percent Occurred	Mean Coverage
Natural Shoreline	Wooded	93%	50%
	Native Herbaceous	100%	40%
	Shrub	7%	1%
Disturbed Shoreline	Cultivated Lawn	28%	8%
	Exposed soil	4%	1%
	Hard Structure	7%	1%

Since 1995, wooded cover has increased and native herbaceous growth and shrub cover has decreased. Cultivated lawn has decreased in mean coverage since 1995 (Table 4). Some of the change in shoreline cover may reflect shoreline restoration projects on Squaw Lake.

Table 4. Change in Mean Coverage of Shoreline Land Use, 1995-2001

		1995	2001
Natural Shoreline	Wooded	21%	50%
	Native Herbaceous	61%	40%
	Shrub	6%	1%
Disturbed Shoreline	Cultivated Lawn	11%	8%
	Exposed soil	1%	1%
	Hard Structure		1%

MACROPHYTE DATA
SPECIES PRESENT

A total of 25 different species of macrophytes were found during the 1986-2001 studies: 17 emergents species, 3 floating leaf species, and 5 submergent species (Table 5).

No endangered, threatened or non-native species were found. One species of special concern was found in Squaw Lake: *Ceratophyllum echinatum.*

Table 5. Squaw Lake Aquatic Plant Species, 1986-2001

Scientific Name	Common Name	I. D. Code
Emergent Species		
1) *Alisma triviale* Pursh	northern water plantain	alitr
2) *Bidens* sp.	bur marigold	bidsp
3) *Carex rostrata* Stokes.	sedge	carro
4) *Dulichium arundinaceum* (L.) Britton	three-way sedge	dular
5) *Eleocharis palustris* L.	creeping spikerush	elepa
6) *Glyceria striata* (Lam.) A. Hitchc.	fowl manna grass	glyst
7) *Iris virginica* L. var. *shrevei* (Small) E. Anderson.	iris	irivi
8) *Lysimachia hybrida* Michx.	hybrid loosestrife	lyshy
9) *Phalaris arundinacea* L.	reed canary grass	phaar
10) *Polygonum amphibium* L.	smartweed	polam
11) *Sagittaria rigida* Pursh.	sessile-fruited arrowhead	sagri
12) *Scirpus fluviatilis* (Torr.) A. Gray.	river bulrush	scifl
13) *Scirpus validus* Vahl.	softstem bulrush	sciva
14) *Sparganium eurycarpum* Engelm.	giant bur-reed	spaeu
15) *Stachys palustris* L.	hedge-nettle	stapa
16) *Typha angustifolia* L.	narrow-leaf cattail	typan
17) *Typha latifolia* L.	common cattail	typla
Floating leaf Species		
18) *Lemna minor* L.	lesser duckweed	lemmi
19) *Nuphar variegata* Durand.	yellow pond lily	nupva
20) *Nymphaea odorata* Aiton.	white water lily	nymod
Submergent Species		
21) *Ceratophyllum echinatum* A. Gray.	spiny coontail	cerec
22) *Eleocharis acicularis* (L.) Roemer & Schultes.	needle spikerush	eleac
23) *Elodea canadensis* Michx.	common waterweed	eloca
24) *Nitella* sp.	nitella	nitsp
25) *Potamogeton pusillus* L.	slender pondweed	potpu

FREQUENCY OF OCCURRENCE

Lemna minor was the most frequently occurring species in Squaw Lake in 1986, 1992 1995 and 1998; *Elodea canadensis* was the most frequent species in 1989, 1992 and 1995 (with *L. minor*); *Phalaris arundinacea* and *Eleocharis acicularis* were the most frequently occurring species in 2001 (Table 6).

Table 6. Frequencies of Prevalent Macrophytes in Squaw Lake 1986-2001

Species	1986	1989	1992	1995	1998	2001
Lemna minor	14%	44%	60%	58%	22%	10%
Eleocharis acicularis	9%				1%	16%
Elodea canadensis		67%	54%	58%	2%	1%
Phalaris arundinacea	1%	17%	23%	27%		18%

Filamentous algae has been a concern in Squaw Lake. It forms dense mats on top of the sediments. These mats of algae were especially evident in 1986, 1989 and 1995. As these mats of algae age, they float to the water surface, obstructing navigation and decompose, creating foul odors. The frequency of filamentous algae at sample sites has cycled up and down between 1986 and 2001 (Figure 5). The occurrence of filamentous algae was highest in 1992 and lowest in 2001 (Figure 5).

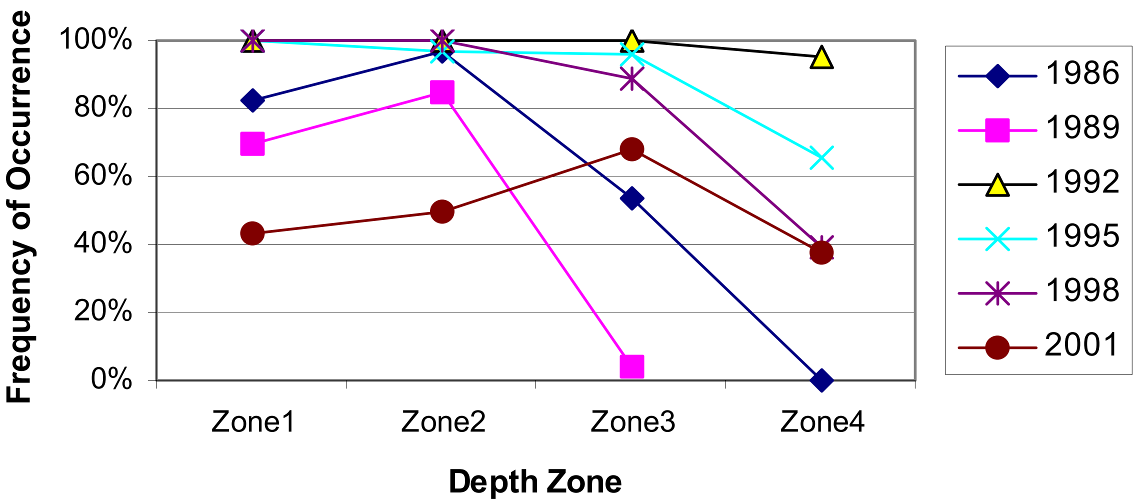


Figure 5. Occurrence of filamentous algae by depth zone, 1986-2001

A heavy scum of planktonic algae occurred at 15% of the sites in 2001.

DENSITY

Lemna minor had the highest mean density in 1986, 1992, 1995 and 1998; *Elodea canadensis* had the highest mean density in 1989 in Squaw Lake (Table 7). *Eleocharis acicularis* had the highest mean density in 2001.

Table 7. Densities of Prevalent Macrophytes in Squaw Lake 1986-2001

Species	1986	1989	1992	1995	1998	2001
Lemna minor	0.39	1.10	1.57	1.66	0.35	0.22
Eleocharis acicularis	0.19				0.01	0.32
Elodea canadensis		1.90	1.17	1.57	0.02	0.02

DOMINANCE

The dominance value illustrates how dominant a species is in its community (Figure 6). *Lemna minor* was the dominant species in 1986 and 1992 – 1998; *Elodea canadensis* was not found the first year, but in 1989 was the dominant species. During 1989-1995, *L. minor* and *E. canadensis* were either dominant or sub-dominant. *Polygonum amphibium* was the sub-dominant species in 1998.

Eleocharis acicularis became the dominant species in 2001, with *Phalaris arundinmacea* as the sub-dominant species (Figure 6). *Eleocharis acicularis* had been the sub-dominant species in the first study in 1986, but disappeared from the community until 1998.

The dominance of "other species" has been increasing since the studies started in 1986. This suggests a better distribution of the aquatic plant community.

Figure 6. Dominance values of the most prevalent macrophytes in Squaw Lake.

DISTRIBUTION

In 1986, aquatic plants were found only in the emergent zone or as free-floating plants in bays.

In 1989 and 1992, rooted aquatic plants were found throughout the littoral zone up to 10.5 to 11.5 feet.

In 1995, rooted aquatic plants were still found through out the littoral zone, but only up to 7.5 feet. Over 7.5 feet, only free-floating species were found.

In 1998, emergent vegetation was found throughout the lake in the shallow zone and rooted submergent vegetation occurred in very scattered locations, only to a maximum depth of 3.5 feet.

In 2001, emergent and rooted submergent vegetation was found throughout the lake, to a maximum depth of 2 feet.

The percentage of sites with rooted vegetation in Squaw Lake increased from the lowest percentage in 1986 to the highest percentage in 1989-95. The shallow depth zone (0-1.5ft) has been the zone with the greatest percent of rooted vegetation in all years (Figure 7).

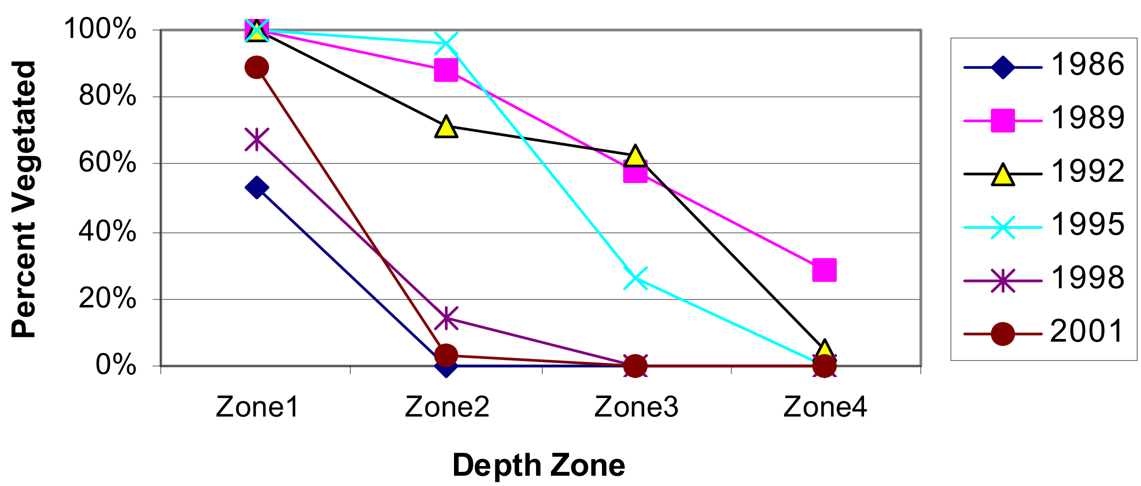


Figure 7. Percentage of sites with rooted vegetation.

The highest total occurrence (Figure 8) and total density (Figure 9) of aquatic macrophyte growth was found in the 0-1.5ft depth zone during all the study years. The occurrence and density of aquatic plants decreased with increasing depth in all years. The total occurrence and total density of plant growth increased steadily from the lowest in 1986 to the highest in 1995, but decreased dramatically in 1998, increasing in the shallow zone in 2001 (Figure 8, 9).

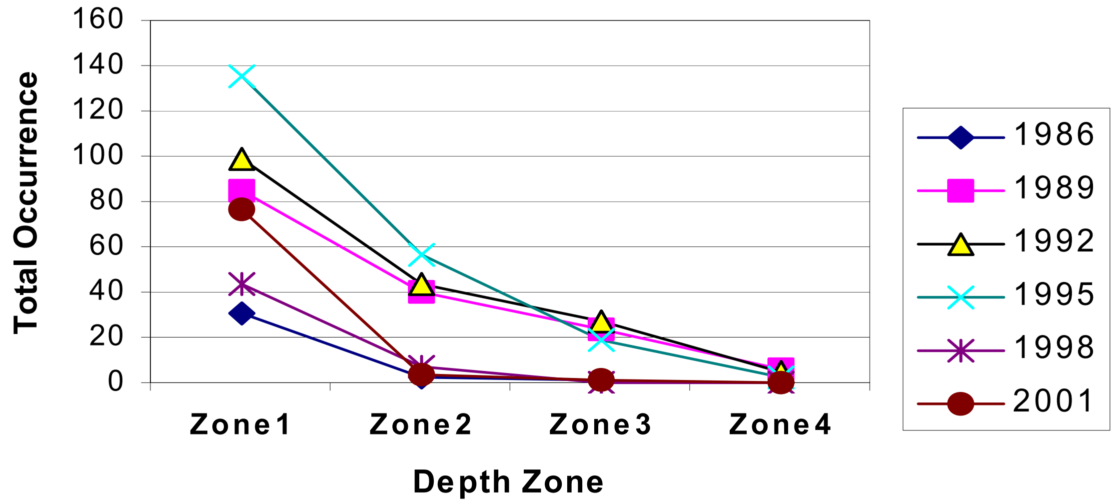


Figure 8. Total occurrence of macrophytes by depth zone.

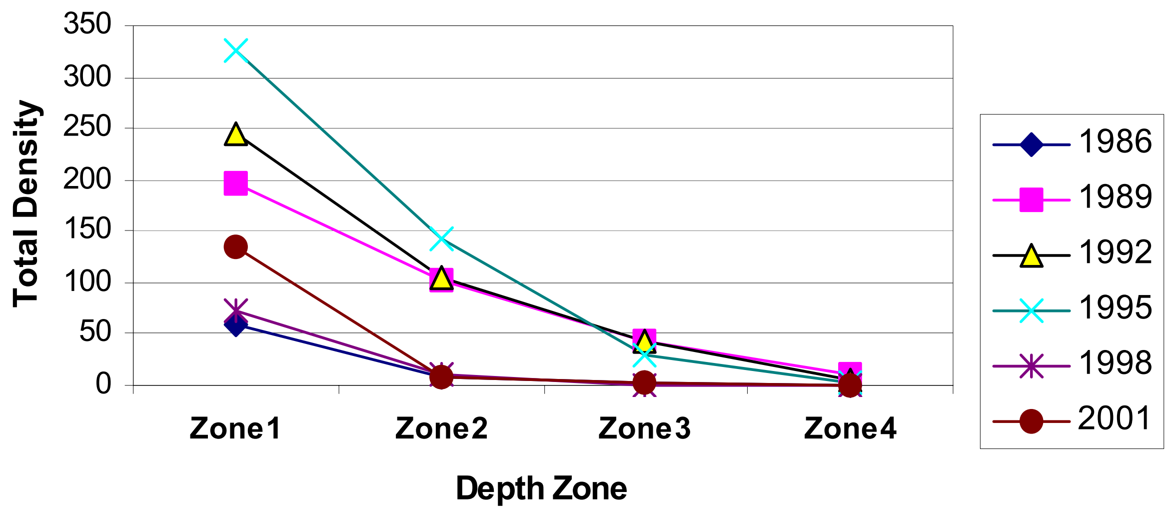


Figure 9. Total density of macrophytes by depth zone.

Lemna minor was usually the dominant species in all depth zones in Squaw Lake (Appendices I-XII), many times occurring as the only species in a depth zone, except for a few instances:

1) In 1986 and 1998, *L. minor* shared dominance with an emergent, *Polygonum amphibium*, in the 0-1.5ft depth zone.

2) In 1995, *L. minor* shared dominance with another emergent, *Phalaris*

arundinacea, in the 0-1.5ft depth zone.

3) In 2001, *P. arundinacea* and *Eleocharis acicularis* were co-dominant in the 0-1.5ft depth zone.

4) *Elodea canadensis* was the dominant species in the 1.5-20ft depth zone in 1989, in the 1.5-10ft depth zone in 1992 and in the 1.5-5ft depth zone in 1995. These three years were the years that *E. canadensis* exhibited its greatest growth.

Elodea canadensis was not found in 1986. During 1989-1995, it was found at its highest frequency and density in the 0-5ft depth zone (Figure 10, 11). Its frequency and density decreased in the 5-20ft depth zone. *E. canadensis* decreased in 1998 and 2001 and was found at a very low frequency and density (Figure 10, 11).

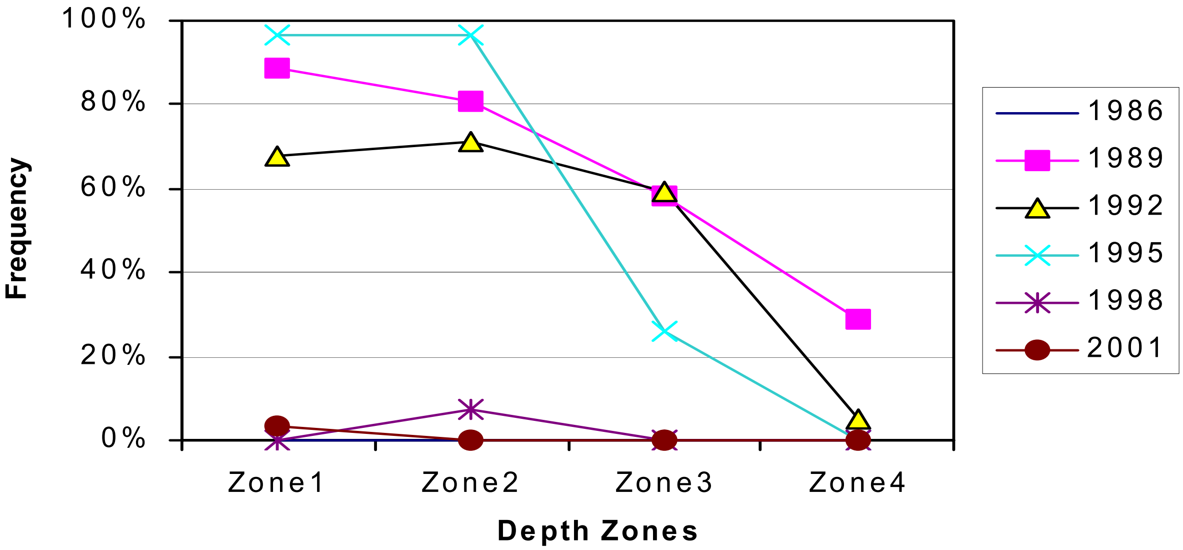


Figure 10. Frequency of *Elodea canadensis* by depth zone in Squaw Lake, 1986-2001.

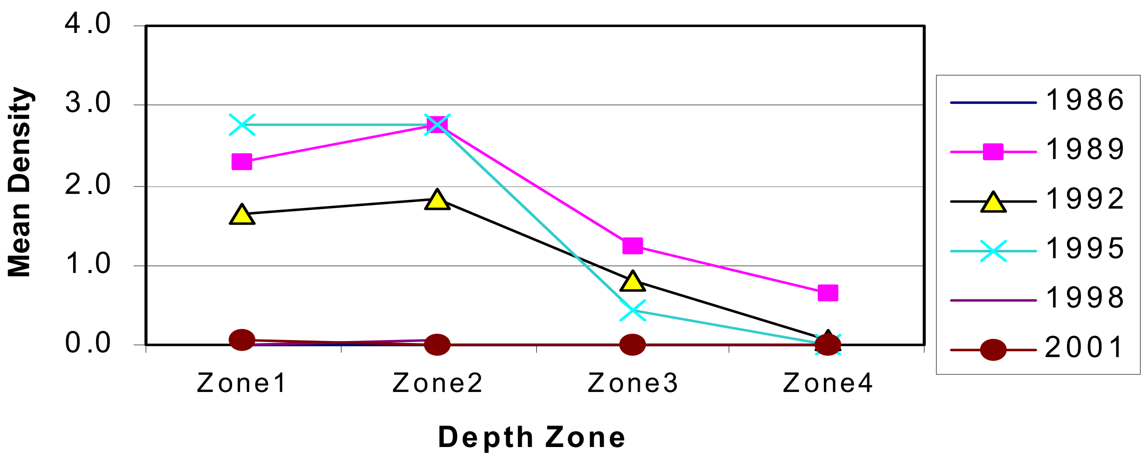


Figure 11. Density of *Elodea canadensis* by depth zone in Squaw Lake 1986-2001.

Lemna minor has had its highest frequency and density in the 0-1.5 foot depth zone (Figure 12, 13). Its frequency and density decrease steeply with increasing depth. The frequency and density of *Lemna minor* was highest during 1992-1995 and lowest in 1986 and 2001. (Figure 12, 13).

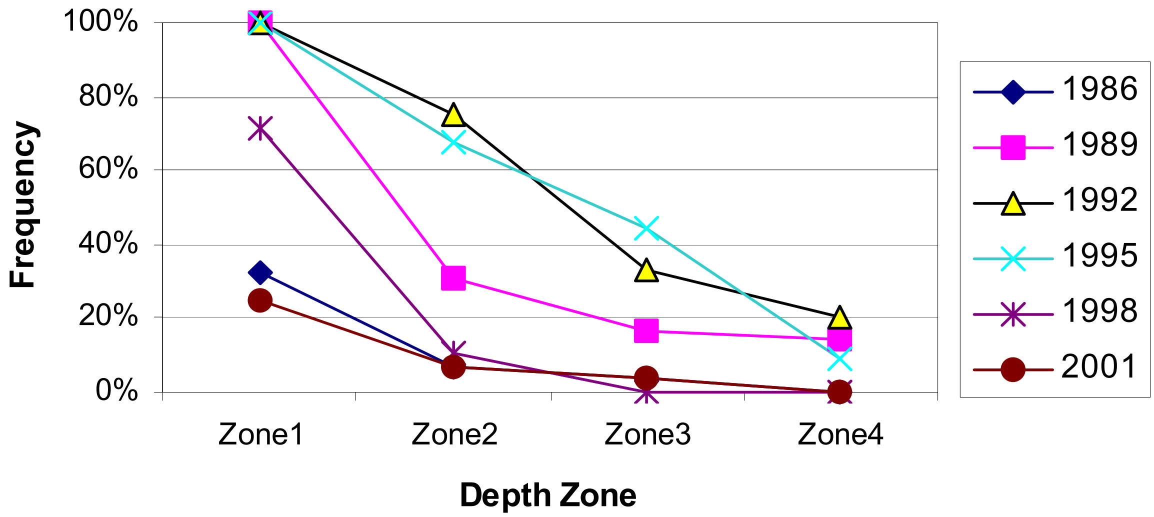


Figure 12. Frequency of *Lemna minor* by depth zone, 1986-2001.

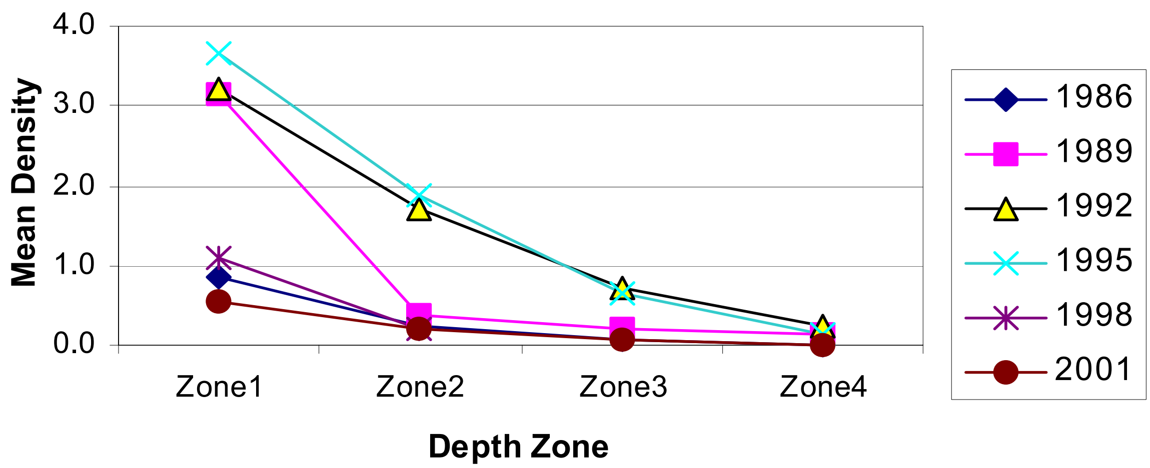


Figure 13. Density of *Lemna minor* by depth zone, 1986-2001.

SEDIMENT INFLUENCE

Some aquatic plants depend on the sediments in which they are rooted for required nutrients. The richness or sterility, density and texture of the sediment will influence the type and abundance of species that can survive in a location.

The availability of mineral nutrients for plant growth is highest in sediments of intermediate density, such as silt (Barko and Smart 1986). Silt was the most prevalent sediment in Squaw Lake in 2001; however, only 15% of the sites with silt were vegetated (Table 8). Silt would likely support more plant growth in Squaw Lake, but silt sediment in Squaw Lake occurred more frequently at depths greater than 5 feet (Table 1). The scarcity of vegetation was likely due to light availability and not sediment type.

Sand and gravel sediments are less favorable to plant growth because they are high-density sediments. However, sand, sand/rock, rock and sand/gravel sediments supported the most plant growth in Squaw Lake (Table 8). Sites with high-density sediments were more prevalent at depths less than 5 feet (Table 1) and the more abundant plant growth was likely due to greater light availability and not sediment type.

Table 8. Sediment Influence, 2001

		Occurrence at Sample sites	**Percent of sediment type vegetated**
Soft Sediments	Silt	40%	**15%**
	Muck	6%	**17%**
Mixed Sediments	Sand/silt	12%	**25%**
	Silt/rock	3%	**0%**
Hard Sediments	Sand/rock	16%	**62%**
	Sand	9%	**33%**
	Rock	9%	**56%**
	Sand/gravel	3%	**100%**

MACROPHYTE COMMUNITY AND CHANGES IN THE COMMUNITY

Significant changes have occurred in the composition of the aquatic plant community in Squaw Lake.

The Coefficients of Community Similarity indicate that the 1986 and 1989 aquatic macrophyte communities in Squaw Lake were significantly different, only 39% similar (Table 9).

The plant community then appeared to stabilize during 1989-1995, 82 - 84% similar. Significant change again occurred between 1995 - 2001; the communities were only 53% and 30% similar (Table 9).

Table 9. Coefficients of Community Similarity

Years Compared	Coefficient	% Similar
1986-89	0.39 *	39%
1989-92	0.82	82%
1992-95	0.84	84%
1995-98	0.531 *	53%
1998-2001	0.301 *	30%
1986-2001	0.424 *	42%

* - Coefficients less than 0.75 indicates a significant difference between the two communities.

The changes in the aquatic plant community over the sixteen years that Squaw Lake has been studied has accumulated and resulted in the 2001 plant community being 42% similar to the plant community of 1986 (Table 9).

Appendix XIX shows the magnitude of change in the frequency, density and dominance of individual species. Seven species have appeared within the aquatic plant community since the earlier studies, 1 species has disappeared and 9 species appeared since the early studies and disappeared before 2001. Three species have increased since 1986; *Phalaris arundinacea* (reed canary grass) has increased the most, 1373%. Two species have decreased since 1986; *Polygonum amphibium* (water smartweed) has decreased the most, 74%.

Many parameters can be used to measure what changes have occurred within the aquatic plant community.

The number of species found in Squaw Lake in 1986 was low and increased substantially throughout 1989-1995, more than doubling (Table 10). The number of species dropped dramatically in 1998, recovered somewhat in 2001 (Table 10). Simpson's Diversity Index and Floristic Quality also increased during 1986-1995, declined in 1998 and increased in 2001. Floristic Quality measures the lack of disturbance and is discussed later in this document.

The maximum rooting depth of aquatic plants in Squaw Lake has gone through dramatic change. The maximum rooting depth increased from its lowest (1-foot) in 1986, to the greatest maximum rooting depth (11.5 feet) in 1989 and steadily declined since 1989 (Table 10).

The percent of the littoral that was vegetated also increased dramatically from

1986-1989 and declined steadily except for an increase in 2001 (Table 10).

The percentage of sites colonized with emergent and submerging vegetation has undergone cycles of increase and decrease. (Table 10). In every other study, the percent of colonization has increased and then decreased in the next study.

Table 10. Changes in the Macrophyte Community

	1986	1989	1992	1995	1998	2001	Change 1989-02	%Change 1986-2001
Number of Species	7	12	16	17	7	12	5	71.4%
Maximum Rooting Depth	1.0	11.5	10.5	7.5	3.5	2.0	1	100.0%
% of Littoral Zone Vegetated	28.6	81.1	74.8	66.0	29.2	30.9	2.3	8.0%
%Sites/Emergents	16.7	25.6	25.2	30.2	19.8	23.7	7.0	41.9%
%Sites/Free-floating	14.3	44.4	61.2	57.5	21.7	10.3	-4.0	-28.0%
%Sites/Submergent	0.0	68.9	56.3	57.5	2.8	19.6	19.6	
Simpson's Diversity Index	0.73	0.75	0.75	0.80	0.65	0.87	0.14	19.2%
Floristic Quality Index	13.61	17.61	20.66	21.00	13.23	15.01	1.40	10.3%

The predicted maximum rooting depth is calculated from the Secchi Disc readings. The actual maximum rooting depth was less than the predicted depth in 1986, deeper than the predicted rooting depth in 1989-1995, less than the predicted depth in 1998 and equal to the predicted depth in 2002 (Figure 14).

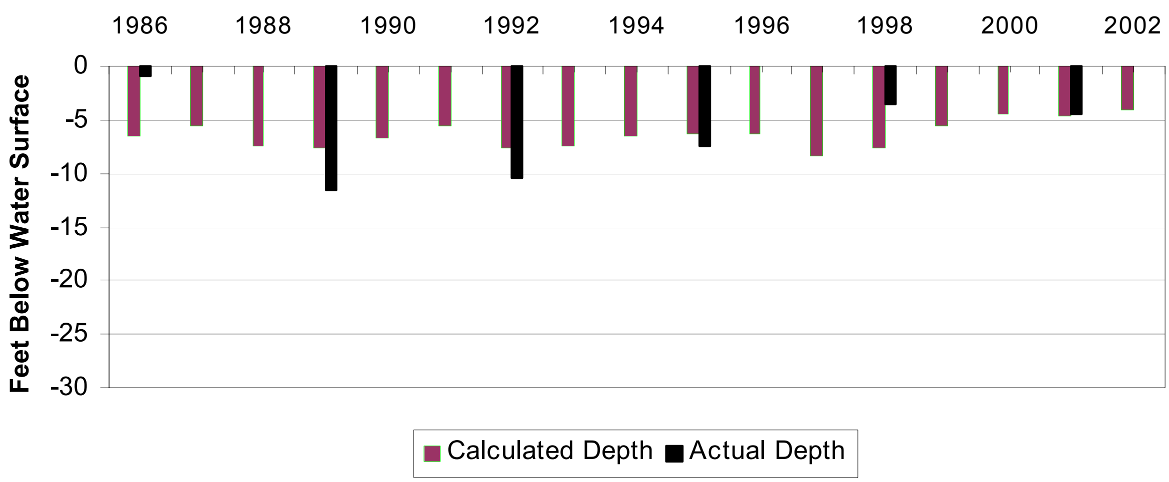


Figure 14. Predicted and actual maximum rooting depth in Squaw Lake, 1986-2001.

According to the Aquatic Macrophyte Community Index (AMCI), the aquatic community in Squaw Lake has been of below average quality (Table 11). The AMCI index indicates that the quality was extremely low in 1986, was improved but still below average in 1989-1995, decreased dramatically to its lowest quality in 1998 and increased slightly in 2001. The AMCIndex suggests that the plant community in 2001 was below average quality, but improved since 1986 (Table 11).

Table 11. Aquatic Macrophyte Community Index for Squaw Lake.

	1986	1989	1992	1995	1998	2001
Maximum Rooting Depth	0	6	6	4	2	0
% Littoral Zone Vegetated	6	10	10	10	6	6
Simpson's Diversity Index	7	8	8	8	7	9
Relative Frequency of Submersed Species	3	6	3	1	1	3
Relative Frequency of Sensitive Species	2	0	0	2	0	4
# of Taxa (reduced by exotic)	2	4	6	6	2	4
Total	20	34	33	31	18	26

The shallow depth of rooting, the low ratio of submergent vegetation, the low number of species and scarcity of sensitive species limit the quality of the aquatic plant community in Squaw Lake (Table 11).

The Average Coefficients of Conservatism for Squaw Lake have remained in the lowest quartile for Wisconsin lakes and within the lowest quartile for lakes in the North Central Hardwood Region, except during 1992-1995. Squaw Lake was below average for lakes in the North Central Hardwood Region 1992-1995 (Table 12). This suggests that the plant community in Squaw Lake was in the group lakes in Wisconsin most tolerant of disturbance. This is likely due to being subjected to disturbance.

Table 12. Floristic Quality and Coefficient of Conservatism of Squaw Lake, Compared to Wisconsin Lakes and Northern Wisconsin Lakes.

	(C) Average Coefficient of Conservatism †	(I) Floristic Quality ‡
Wisconsin Lakes *	5.5, 6.0, 6.9	16.9, 22.2, 27.5
NCHR *	5.2, 5.6, 5.8	17.0, 20.9, 24.4
Squaw Lake, 1986-2001		
1986	5.14	13.61
1989	5.08	17.61
1992	5.33	20.66
1995	5.25	21.00
1998	5.00	13.23
2001	4.33	15.01

*** -** Values indicate the highest value of the lowest quartile, the mean and the lowest value of the upper quartile. (NCHR) The North Central Hardwoods Region, the region in which Squaw Lake is located

† - Average Coefficient of Conservatism ranged from a low of 2.0 (the most disturbance tolerant) to a high of 9.5 (least disturbance tolerant)

‡ - The lowest Floristic Quality in Wisconsin was 3.0 (farthest from an undisturbed condition) and the high was 44.6 (closest to an undisturbed condition).

The Floristic Quality of the plant community in Squaw Lake remained in the lowest quartile for Wisconsin Lakes. Compared to lakes in the North Central Hardwood Region, Squaw Lake was in the lowest quartile in 1986, below the mean 1989-95 and in the lowest quartile again in 1998-2001 (Table 12). This indicates that the plant community in Squaw Lake was in the group of lakes in the state and the region that is furthest from an undisturbed condition, except in 1989-1995, when it was less disturbed but still farther from an undisturbed condition that the average lake in the North Central Hardwood Region Lake.

Disturbances can be of many types:

1) Biological disturbances include the introduction of a non-native or invasive plant species, grazing from an increased population of aquatic herbivores and destruction of plant beds by the fish population.
2) Physical disturbances to the plant beds result from activities such as boat traffic, plant harvesting, chemical treatments, the placement of docks and other structures and fluctuating water levels.
3) Indirect disturbances can be the result of factors that impact water clarity and thus stress species that are more sensitive: resuspension of sediments, sedimentation from erosion and increased algae growth due to nutrient inputs.

IV. DISCUSSION

Based on water clarity and concentrations of chlorophyll and phosphorus, Squaw Lake has been a hypereutrophic lake with poor to very poor water quality and clarity during the study period (1986-2001). Squaw Lake experiences severe planktonic and filamentous algal blooms and appears to be nitrogen limited at times. This means that additions of nitrogen or phosphorus can promote algae growth.

Phosphorus has been increasing slightly since 1999. However, since 1986, chlorophyll and phosphorus have declined and water clarity has increased.

The ratio of watershed area to lake size for Squaw Lake is greater than 10:1. Watershed ratios of this size tend to have water quality problems. This is exacerbated by a high percentage of cropland in the watershed, 61%. Nutrient run-off from cropland, winterspreading manure and nutrient recycling from the lake sediment were identified as the major nutrient sources to Squaw Lake.

A large portion of the shoreline on Squaw Lake is protected by native vegetation, covering 91% of the shore in 2001. Natural shoreline has increased from a mean coverage of 88% in 1995.

Disturbed shoreline is commonly occurring, but the coverage of cultivated lawn and other disturbed cover have decreased since 1995.

Shoreline restoration demonstration sites have been established on riparian properties on Squaw Lake and are contributing to the increase in natural shoreline. These sites will provide beauty and wildlife habitat along the Squaw Lake shoreline and, at the same time, help protect water quality in Squaw Lake.

Algae and Copper Treatments

Filamentous algae, especially, has been a concern in Squaw Lake. In some years, the dense mats were observed carpeting the sediment at 46-99% of the sample sites. Occurrence of filamentous algae at the sampling sites has cycled, but has remained high. Although its occurrence is high, the frequency of filamentous algae was lowest in 2001 (50%).

Past attempts to control algae blooms by applying copper sulfate had no long-term impact on algae growth and may have made the situation worse. Nearly 7000 pounds of copper sulfate were applied to Squaw Lake during 1969-1984. Copper precipitates from the water very quickly and kills only the algae cells that it comes in contact with as it precipitates. Algae continue to multiply from the surviving algae cells and another algae bloom can occur within 10 days.

Copper can exacerbate algae problems by reducing members of the lake food chain that eat algae. Zooplankton (free-floating invertebrates) and mollusks (clams and snails) are the natural grazers of algae. These aquatic organisms are sensitive to copper, even at approved treatment rates. The copper kills the zooplankton as it is applied. The build up of copper in the sediment is toxic to the mollusk populations. This results in less algae being eaten through the natural food chain.

Nutrient runoff, phosphorus and nitrogen, are feeding the algae blooms in Squaw Lake. Controlling these nutrients will be necessary to reduce the frequency and severity of the algae blooms.

Abundance of Plant Growth

Plant growth in Squaw Lake would be favored by abundant nutrients in the lake, gradual slopes of the littoral zone and shallow depths of the bays and dominance of favorable silt sediments. However, poor water clarity, soft water, steeply sloped littoral zone on the east and west shores and fluctuating water levels would limit plant growth. Also, the occurrence of favorable silt sediments is more common at depths greater than 5 feet, below the photic zone in Squaw Lake. Less favorable sand and rock sediments are dominant in the shallow zone would limit plant growth.

The frequency of vegetated sites, the total occurrence of aquatic plants and the total density of aquatic plants has been greatest in the 0-1.5 ft. depth zone and decreases rapidly with increasing depth. This suggests that poor water clarity is a major factor impacting distribution of aquatic plant growth in Squaw Lake.

Composition and Quality of the Aquatic Plant Community

25 species have occurred in Squaw Lake, more than half of the species (17) have been emergent species.

Lemna minor (duckweed) and/or *Elodea canadensis* (common waterweed) were the dominant species in 1986-1998. *L. minor* had been a dominant or sub-dominant species during 1986-1998, especially in the 1.5-10ft depth zone; *E. canadensis* was prevalent only during 1989-1995.

Phalaris arundinacea (reed canary grass) and *Polygonum amphibium* (water smartweed) were sub-dominant in some years. These species have been the most frequent species in the 0-1.5ft depth zone and are indicators of disturbance, likely the fluctuating water levels.

Elocharis acicularis, a turf-forming species, and *Phalaris arundinacea* (reed canary grass) became the dominant species in 2001. The dominance of "other species" species has increased since 1986, confirming the increase in species diversity.

In 2001, the diversity of plants, measured by Simpson’s Diversity Index, was good; the quality of the aquatic plant community, measured by AMCIndex was below average. The low maximum rooting depth, low ratio of submergent species, limited number of species and lack of sensitive species are limiting the quality of the aquatic plant community.

Some type of disturbance is impacting the aquatic plant community in Squaw Lake. The Average Coefficient of Conservatism and Floristic Quality Index indicate that the plant community in Squaw Lake is among the group of lakes in Wisconsin and the North Central Hardwood Region that are most disturbance tolerant and farthest from an undisturbed condition. This suggests that Squaw Lake is among the lakes that have experienced the most disturbance.

Fluctuating water levels, poor water clarity, abundant algae and the dense mats of filamentous algae are likely the major disturbance factors in Squaw Lake.

Changes in the Aquatic Plant Community

The aquatic plant community that was first surveyed in 1986 was only 42% similar to the current aquatic plant community of 2001. The composition of the aquatic plant community changed significantly between 1986 and 1989. The 1989-1995 communities appeared to be in a period of stabilization, with no significant change. However, significant change occurred again between 1995 and 2001 aquatic plant communities.

Because the 2001 community is more similar to the 1986 plant community than to the 1998 plant community, it suggests a return to the 1986 plant community.

1986

Vegetation was most sparse throughout the lake in 1986; the 1986 survey recorded the fewest number of aquatic plant species, lowest percentage of vegetated sites, lowest percentage of sites with rooted vegetation, lowest total occurrence of aquatic plants, lowest total density of plants, shallowest maximum rooting depth (1 ft) and lowest coverage of emergent and submergent vegetation. The Average Coefficient of Conservatism and Floristic Quality Index placed Squaw Lake among the group of lakes in the state and region most tolerant of disturbance and farthest from and undisturbed condition.

1989-1995

The abundance of aquatic vegetation increased during the 1989-1995 time period, with dramatic increases in number of species, percent coverage of aquatic vegetation and maximum rooting depth. In 1995, the aquatic plant community appeared to be at its highest abundance: the greatest total occurrence of plants, highest total density of plant growth, greatest number of species and greatest coverage of emergent vegetation. The plant community in 1989-1995 appeared to be subjected to less disturbance tolerant than the plant community in 1986 and 1998-2001.

The Average Coefficients of Conservatism and Floristic Quality Indices suggested that the aquatic plant community during 1989-1995 was less impacted by disturbance.

1998-2001

In 1998, there was a dramatic reversal in the aquatic plant community in Squaw Lake; nearly every measure of the aquatic plant community decreased to the sparse level of plant growth found in 1986. The number of species decreased and species diversity decreased to its lowest. The 1998 aquatic plant community was at its lowest quality (AMCI) and highest disturbance (FQI).

In 2001, the aquatic plant community improved somewhat and species diversity increased to its highest.

These changes may be due to the fluctuating water levels in Squaw Lake; plant growth can not immediately adjust to new water levels. This is likely the reason that the actual maximum rooting depth in Squaw Lake has fluctuated above and below the predicted maximum rooting depth.

V. CONCLUSIONS

Squaw Lake has been a hypereutrophic lake with very poor water quality. High nutrient levels support the growth of abundant planktonic and filamentous algae that cause very poor water clarity.

Since 1986, the concentration of phosphorus (nutrients) and chlorophyll (algae) has decreased and the water clarity has increased. The occurrence of filamentous algae was lowest in 2001.

Aquatic plant growth in Squaw Lake is limited by the soft water, steep littoral zone in some portions of the lake, fluctuating water levels, less favorable sediments for plant growth in the shallow zones and poor water clarity.

The aquatic plant community has undergone changes during 1986-2001. The Coefficients of Community Similarity indicate that the composition of the aquatic plant community changed significantly, between 1986-1989 and 1995-2001; the 1989-1995 communities were more similar.

The plant community has changed from:

A community of sparse plant growth, fair diversity and below average quality in 1986;

to a plant community with more abundant plant growth, average diversity and nearly average quality in 1989-1995;

and finally to a plant community of sparse plant growth, good diversity and below average quality in 1998-2001.

The species diversity and quality in 1998 was the lowest of any year sampled.

In 2001, plant growth increased and the plant community had the highest species diversity. The dominance of "other species" species has increased since 1986, confirming the increase in species diversity.

Species that are tolerant of poor water clarity have increased from 1986-2001. *Phalaris arundinacea* has increased the most. *Polygonum amphibium* has decreased the most, likely due to the current, higher water levels.

The Floristic Quality Index (FQI) indicates that some type of disturbance is occurring in Squaw Lake. FQI places Squaw Lake in the lowest quartile of lakes in Wisconsin and the North Central Hardwood Region in regard to disturbance. This means that Squaw Lake is among the group of lakes most impacted by disturbance. Fluctuating water levels and poor water clarity caused by the abundant algae growth are likely the major disturbance factors and are determining the quality and composition of the aquatic plant community in Squaw Lake.

ALGAE GROWTH

The year with the lowest frequency of filamentous algae coincided with the year that had the greatest distribution of plant growth (highest percentage sites with aquatic plants, highest percentage of sites with rooted aquatic plants and the greatest maximum rooting depth). Either:

1) Decreased algal growth was a result of the more abundant plant growth. Dense algae growth can shade and retard the growth of aquatic plants.

or

2) Increased plant growth resulted from better clarity due to decreased algal growth. Aquatic plants and algae compete for nutrients. Aquatic plants produce phytotoxins, phenolic compounds, that can suppress algal growth (Kahl 1993, Rejmankova 1989).

POOR WATER CLARITY

The poor water quality in Squaw Lake is reflected in the plant community. Plant growth is found mainly in the 0-1.5ft depth zone.

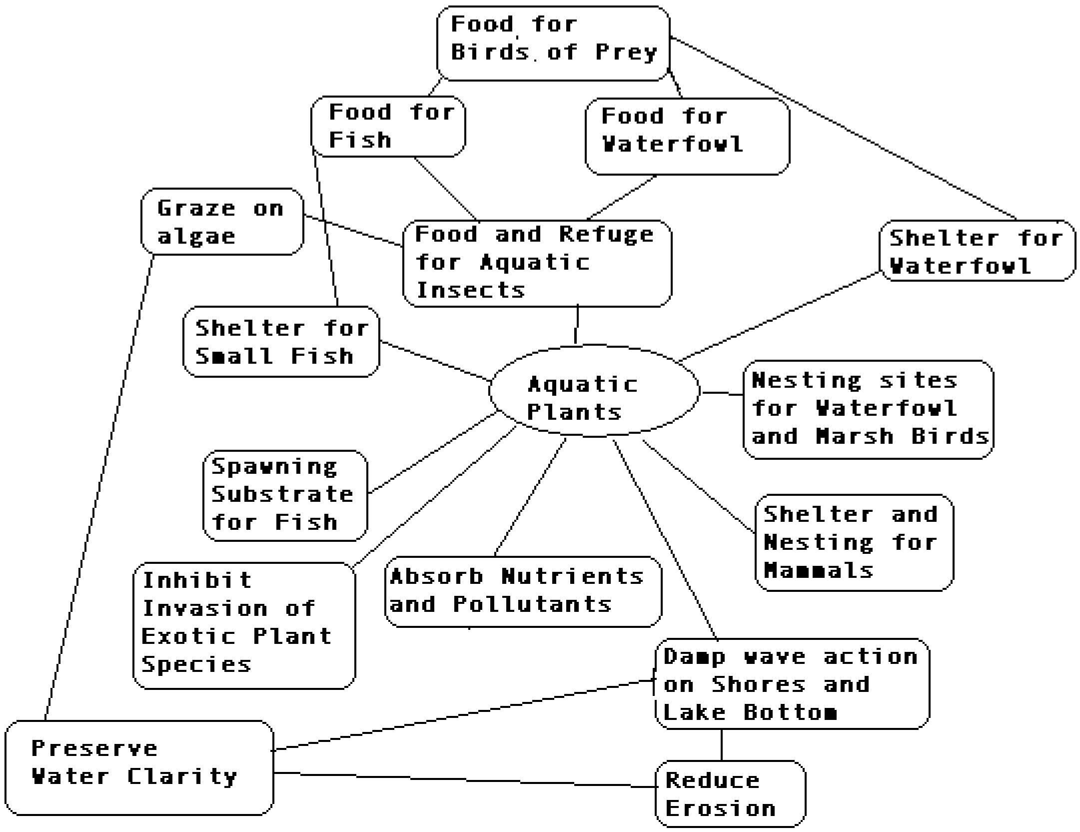
Even during years with the best plant growth, the dominant species have been emergents in the shallow water and species adapted to poor water clarity: *Elodea canadensis* and *Lemna minor* were dominant in 1986-1998. *Elocharis acicularis*, a turf-forming species, and *Phalaris arundinacea* (reed canary grass) became the dominant species in 2001.

FLUCTUATING WATER LEVELS

The actual maximum rooting depth in Squaw Lake has fluctuated above and below the predicted maximum rooting depth that is based on water clarity. This may be caused by the inability of plant growth to immediately adjust to new water levels.

Healthy plant communities improve water quality in many ways:

1) aquatic plants trap nutrients, debris, and pollutants entering a water body;
2) aquatic plants may absorb and break down the pollutants;
3) aquatic plants reduce erosion by stabilizing banks and shorelines, stabilizing bottoms, and reduce wave action that could resuspend sediments;
4) aquatic plants remove nutrients that would otherwise be available for algae



blooms (Engel 1985).

The plants present in Squaw Lake provide habitat benefits for fish and wildlife. However, only 27% of the sites supported rooted vegetation in 1998. This level of vegetation is appropriate for largemouth bass, but not for young fish and panfish that hold an important position in the food chain of a lake. If 27% of the littoral zone in Squaw Lake is vegetated with rooted vegetation, approximately 13% of the entire lake surface has rooted vegetation. This is less than the desired 20-30% vegetation over an entire lake (Miller et. al. 1989).

Pike, perch, and largemouth bass require vegetation for cover when young. Vegetation is the key to habitat for black crappies, bluegills, and sunfish (Dibble et. al. 1997). Seven to ten times more fish are found in vegetated areas than in open areas (Kilgore et. al. 1993).

Management Recommendations

1) Address algae control through nutrient reduction and not through copper treatments. Copper treatments for algae were discontinued due to their ineffectiveness. The copper treatments did not address the cause of the algae growth. Short-term benefits from the copper treatments can lead to long-term impacts to the food web in the lake.
2) Cooperate with efforts to reduce the nutrient inputs to Squaw Lake.
    a) Cooperate with nutrient management programs in the watershed: responsible placement of manure, conservation practices on cropland. Inputs of nutrients from the watershed must be reduced.
    b) Discontinue any lawn fertilizer use that may be occurring on lakeshore properties.
    c) Maintain septic systems.

Protect and expand natural shorelines. Increased natural shoreline is not only beneficial to the water quality, but also to wildlife habitat.

a) Continue monitoring of the shoreline restoration demonstration sites.
b) Expand the shoreline restoration projects to include more participants.
c) Reduce the amount of cultivated lawn near the shore and allow buffer zones of native vegetation to develop.
d) Re-vegetate eroded areas.
e) Minimize the placement of hard structures and surfaces along the shoreline.

Improved water quality may allow aquatic plant species found at low frequencies to expand and flourish. Better clarity could also allow plants to grow in deeper water where they could help to stabilize the sediment and extend the fish habitat. A plant community with higher diversity and better distribution would provide better habitat for fish and wildlife.